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THE MOST SUITABLE METHOD BETWEEN DTC AND SVDTC METHOD FOR CONTROLING OF IM

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ABSTRACT

Three-phase induction motors are asynchronous speed machines. This machine operates below synchronous speed when motoring and above synchronous speed when generating. These motors are less expensive as compared to synchronous as well as dc motors. The induction motors are cheap, rugged and require less maintenance but in these motors the speed is not controlled as easily as with dc motors. They illustrate large starting current, typically about six to eight times the full load currents. When these motors are lightly loaded, they operate with a poor lagging power factor. Due to the use of these hysteresis comparators, variable switching frequency is obtained and also high torque ripples occur in DTC drives. To overcome the disadvantages of DTC strategy, Direct Torque Control with Space Vector Modulation (DTC-SVM) is used to minimize the electromagnetic torque ripples in induction motor. The main aim of DTC-SVM is to calculate the voltage space vector, which balance the errors of flux and electromagnetic torque. At every sampling period, inverter switching states have been chosen by voltage vector selection block to reduce the flux and electromagnetic torque error.
In this dissertation report, induction motor has been simulated in stationary d-q reference frame and its free acceleration characteristics are drawn. Conventional DTC and SVM-DTC has been described in this report. The comparison is made between the two which results the superiority of SVM-DTC. Literature review has been given for the study of recent improvements in DTC scheme. These improvements are able to beat the drawbacks of conventional DTC. The space vector pulse width modulation technique (SVPWM) is applied to 2 level inverter control. And later in the given thesis SVPWM technique is applied to DTC drive system for the reduction of torque ripples.

KEY WORD: *Space vector pulse width modulation technique (SVPWM), DTC-SVM, space vector, Matlab/Simulink.*

1. INTRODUCTION

In the past, Induction motors have been used in the constant speed applications because their speed control methods have been highly inefficient and expensive. DC drives have been used for variable speed applications. These require frequent maintenance. These presences make them unsuitable for dirty and explosive environments. Conversely, induction motors (squirrel cage induction motors) are lighter, rugged, smaller, cheaper, more efficient, and require low maintenance. Direct torque control drives are finding great interest, since ABB recently introduced the first industrial direct-torque-controlled induction motor drive in the mid-1980‘s, which can work at zero speed also. This is a very significant industrial contribution. ABB has also introduced a DTC based medium voltage drive which is called the ACS1000. These drives are feeding pure sinusoidal voltages and currents to the motor. This is ideal for fans and pumps [7]. Three-phase induction motors are asynchronous speed machines. This machine operates below synchronous speed when motoring and above synchronous speed when generating. These motors are less expensive as compared to synchronous as well as dc motors. The induction motors are cheap, rugged and require less maintenance but in these motors the speed is not controlled as easily as with dc motors. They illustrate large starting current, typically about six to eight times the full load currents. When these motors are lightly loaded, they operate with a poor lagging power factor. In this scheme, there is no requirement of pulse width modulation to directly calculate the motor torque. In DTC scheme there is no modulator used and no need for a tachometer or position encoder which is used to feedback the speed or position of the shaft. It requires the digital signal processing (DSP) hardware. The result is fastest torque response. But the Conventional DTC gives slow response and changed in either direction of flux and electromagnetic torque. It also gives high torque ripples. A no. of techniques has been developed for the advance of torque performance. One of them is space vector modulation (SVM) technique with DTC. A group of German researched presented SVM first in the second half of the 1985s. Since then, lots of work has been done on the SVM technique. This technique has various merits such as, lower switching losses, lower torque ripple,. Also lower Total Harmonic Distortion (THD) in the current. It is easy to apply in the digital systems. At each cycle period, this SVM method is employed to achieve the voltage space vector which is required to compensate the errors of flux and electromagnetic torque. From this DTC-SVM, the torque ripples are drastically reduced and constant switching frequency is obtained.

2. LITERATURE REVIEW

Chee-mun Ong [2] describe the techniques of modeling and simulation of electrical machinery. This shows the circuit model of 3-phase induction machine with all its reference frames. Transient and steady state model for induction machine is also explained. K. L. Shi describes a generalized model and the computer simulation of 3-phase induction motor by using MATLAB/SIMULINK. Construction of induction motor sub-models is also given and in simulink, their implementation is outlined [3]. A direct torque control scheme of machine is given which minimize the torque ripples and maintain the switching frequency constant. In the proposed strategy, by using instantaneous torque equation, an rms torque-ripple equation is derived. An optimal switching instant is determined at each switching cycle, which satisfies the minimum torque-ripple condition [4]. Dorin O. Neacsu [5], presents the base theory of space vector modulation (SVM) applied to a 3-phase voltage source inverter. In this, diverse implementation methods were tried. By application to novel three-phase topologies, the use of space vector modulation (SVM) at 3-phase VSI has been expanded. These topologies are as AC/DC voltage source inverter, DC/AC or AC/DC current source inverter, multilevel converters, matrix converters & so on. Bose B. K [6] describes the steady state performance of induction motor followed by the dynamic model (d-q model) in both synchronous and stationary reference frame. Then, state-space equations are derived mainly for simulation. Also the principle of the sinusoidal Pulse Width Modulation (PWM) with instantaneous current control has been explained. Rashid [7] presented the vector control system. Later he gives an instantaneous torque control with DTC which gives very fast torque response. Jose Rodriguez gives a new method of DTC which is based on load angle control. To obtain the control algorithm, simple equations are used. This makes it easy for implement and understands. Ku. Trupti Deoram Tembhekar [13] describes the speed control methods of three-phase induction machine. The V/f control is highlighted. The scalar control and vector control methods are compared. The performance is also evaluated under variable input-output condition. The simulation results of open and closed loop speed control of motor drives are presented. Here, presents the speed control of vector controlled or field orientation controlled induction motor. The literature on control of induction motor drive is very much diversified over the controlling aspects. The brief review is presented on the subject of new schemes with DTC so as to minimize the torque ripples with the DTC .

3. OBJECTIVE OF THE WORK AND METHEDOLOGY

The objective of the present work is to obtain the reduced torque ripples with constant switching frequency operation. DTC-SVM is developed to improve the torque performance. The aim of SVM is to achieve the voltage space vector required for compensation of the flux and torque errors.

3.1.Modelling and control techniques of induction motor drive

In the past, Induction motors have been used in the constant speed applications because their speed control methods have been highly inefficient and expensive. DC drives have been used for variable speed applications. Now, due to availability of thyristors, power transistors, IGBT (Insulated Gate Bipolar Transistor) and GTO (Gate Turn Off) variable speed induction motor drives are developed. The disadvantages of DC machines are the presence of commutator, brushes etc. These require frequent maintenance. These presences make them unsuitable for dirty and explosive environments. Conversely, induction motors (squirrel cage induction motors) are lighter, rugged, smaller, cheaper, more efficient, and require low maintenance. These motors can also operate in dirty and explosive environments. While variable speed induction motor drives are expensive than dc drives, they are used in many applications such as fans, blowers, conveyers, cranes, traction etc.

In the three-phase induction machines, stator carries a 3-phase balanced distributed winding. The magnetic field of a 2-pole motor has revolved through 360° physical space, when a 3-phase supply completes one full cycle (360° electrical). The motors with 4-poles require two power supply cycles (720° electrical) to complete one revolution (360° mechanical) of the magnetic field. Thus, these motors run slower. In Table 3.1, actual motor parameters are being used by both DC and DTC drives to control speed and torque.

Table 3.1
Comparision of control variables of various drives

DRIVE	CONTROL VARIABLES
DC DRIVES	Armature Current, Field Current
AC DRIVES (PWM)	Voltage, Frequency
DIRECT TORQUE CONTROL	Motor Torque, Motor Magnetizing Flux

Therefore, the dynamic performance is easy & fast. Also in DTC, there is no need of encoder or a tachometer to feedback the speed or position signal. In pulse width modulated AC drives, the control variables are voltage and frequency which needs to go through various stages before being applied to the machine. Therefore, with PWM drives, electronic controller handled the control.

3.2.Conventional direct torque control (DTC)

It is possible to achieve a good dynamic control for the torque by means of Direct Torque Control (DTC) or Direct Self Control (DSC) without using mechanical transducer on shaft. Therefore DSC and DTC are known as "sensor less type" control techniques. In the high power range applications the direct self control scheme is preferable because the low inverter switching frequency can validate higher current distortion. DTC induction motor drive is conceptualized on controlling the stator flux and electromagnetic torque independently. Direct torque control name is derived based on the error in between the reference and the actual values of the flux and torque; it is possible to directly control the inverter states so as to reduce the flux and torque error within limits. DTC based drives doesn't necessitate the coordinate transformation in between stationary and synchronous frame when compared with the field oriented control drives. The instantaneous stator flux and torque is estimated by using voltage and current measurements. Direct torque control utilized an induction motor model to calculate the voltage which is required for achieving the desired output torque.

This direct torque control (DTC) is one such scheme of speed control. In small scale packaging industry requiring servo drive applications, conventional AC drivers aren't capable of providing rapid and smooth variation in speed.

3.3.Principle of Direct Torque Control (DTC)

The 3-phase induction machine electromagnetic torque can be expressed as:

$$T_e = \frac{3P}{2}(\overrightarrow{\lambda_s^s} \times \overrightarrow{I_s^s})$$

Where, $\overrightarrow{I_s^s}$ = Current space vector of stator, $\overrightarrow{\lambda_s^s}$ = Stator flux linkage space vector. Both fixed to the stationary frame (fixed to the stator).

P= Number of pairs of poles

$\overrightarrow{\lambda_s^s}$ can be stated as, $\overrightarrow{\lambda_s^s} = \left|\lambda_s^s\right| e^{j\rho_s}$

Where, ρ_s = angle of the stator flux linkage space vector w.r.to the d-axis of the stator reference frame shown in Figure 1.1.

And $\overrightarrow{I_s^s}$ can be expressed as, $\overrightarrow{I_s^s} = \left|i_s^s\right| e^{j\phi_s}$

Equation (4.1) can be expressed as follows:

$$T_e = \frac{3}{2} p \left|\overrightarrow{\lambda_s^s}\right| \left|\overrightarrow{I_s^s}\right| \sin(\phi_s - \rho_s)$$

Where, ρ_s= Stator flux angle and ϕ_s = Stator current angle in the stationary frame.

The equations of voltage for the induction motor shows that, if the angle ρ_s is changed by keeping the stator flux linkage space vector $\overrightarrow{\lambda_s^s}$ constant for a given values of the rotor speed, then the torque can be changed rapidly.

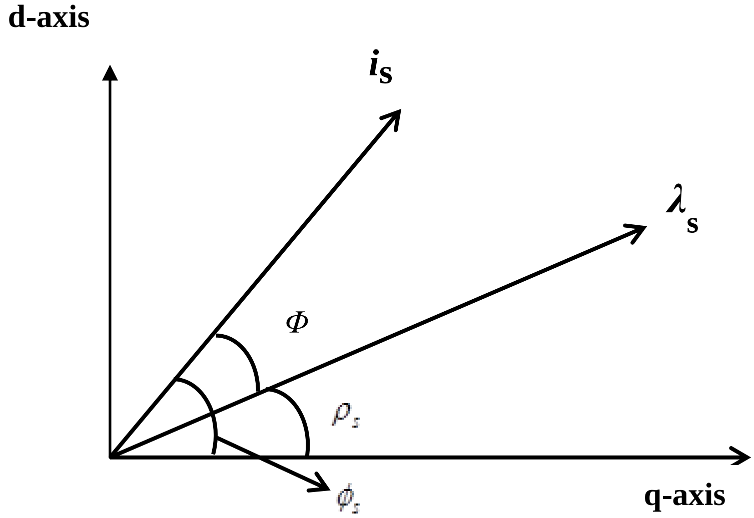


FIG. 1.1. Stator Current and Stator Flux-Linkage Space Vector

3.3.1. Mathematical Presentation

The rotor current space vector may be expressed in terms of the stator flux linkage vector in stationary reference frame and is given by:

$$\overrightarrow{I_s^s} = \frac{(\overrightarrow{\lambda_s^s} - L_s \overrightarrow{I_s^s})}{L_m}$$

By using equations:

$$\overrightarrow{\lambda_r^s} = L_r \overrightarrow{I_s^s} + L_m \overrightarrow{I_s^s}$$

By putting equation the rotor flux linkage space vector can be defined as:

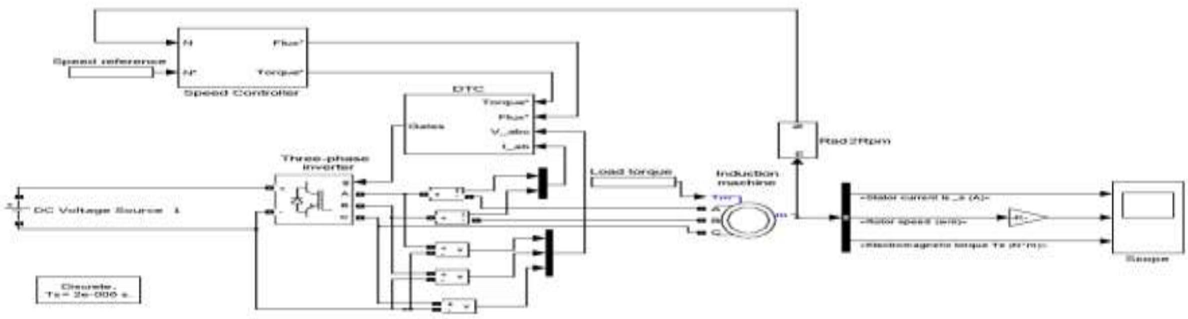
$$\overrightarrow{\lambda_r^s} = \frac{L_r}{L_m}(\overrightarrow{\lambda_s^s} - L_s \overrightarrow{I_s^s})$$

Now, by substituting above two equations in rotor voltage equation which is expressed in stationary reference frame (i.e. $0 = R_r \overrightarrow{I_s^s} + \frac{d}{dt}\overrightarrow{\lambda_r^s} - j\omega_r \overrightarrow{\lambda_r^s}$), we can express the rotor voltage equation in terms of $\overrightarrow{I_s^s}$ and $\overrightarrow{\lambda_s^s}$ .This can be used to express the stator current space vector ($\overrightarrow{I_s^s}$) in terms of the stator flux linkage space vector ($\overrightarrow{\lambda_s^s}$). This stator current space vector expression ($\overrightarrow{I_s^s}$) is then put in equation and from that equation we can see that the electromagnetic torque depends upon stator flux-linkage space vector. It also depends on $\rho_{s,}$ which is angle of this stator flux linkage space vector regarding the direct axis (d-axes) of the stationary reference frame. Thus the rapid response time of electromagnetic torque is obtained by imposing the largest $d\rho_s/dt$, keeping the stator flux linkage constant. We can also say that, if this type of stator voltages are impressed on the motor, which quickly revolve the stator flux-linkage space vector in the required position and keep the stator flux constant (for the demanded value), then fast torque control is obtained. Therefore, by controlling the stator flux linkage space vector, torque can be rapidly changed. This stator flux linkage space vector can also be changed by using proper stator voltages that is generated by the inverter. This is the voltage which supplies the induction motor. It can be seen from above that the control of flux and electromagnetic torque is obtained directly by using the proper stator voltages. Due to that, this kind of control is usually referred to as direct torque control.

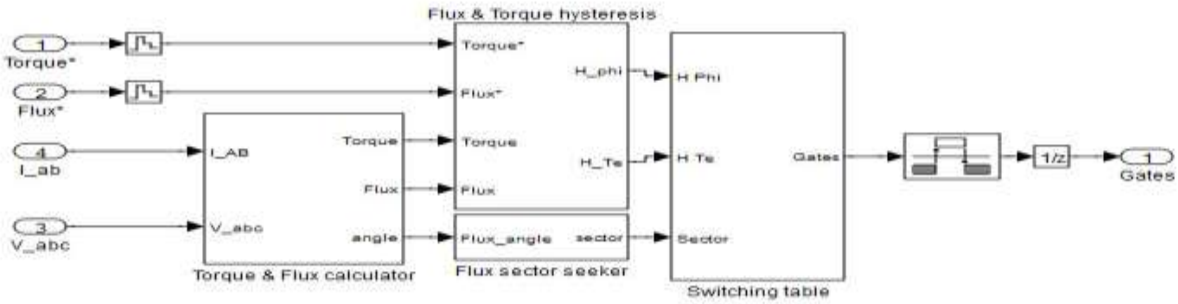
3.4. Simulation Model of Conventional DTC

To show the effectiveness of this control method, simulation has been carried out for an induction motor. The simulation has been done with MATLAB/SIMULINK, that is a tool for simulation. It has been considered that:

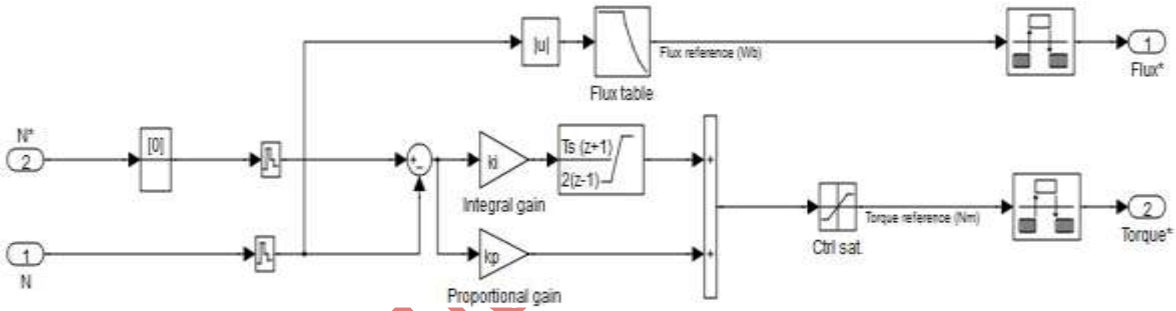
- At t = (0; 1.5) sec, the speed reference prescribed to (800; 1000) rpm.
- The load torque prescribed to (0; 12) Nm at t= (0; 1.5) sec. with step variation. The time variations of the main mechanical and electrical variables, specific to the presented drive (the rotor speed N, the electromagnetic torque (Te) and the stator current i_{sa}) is obtained and it represents in Figure.



Simulation Model of Conventional DTC Induction Motor Drive



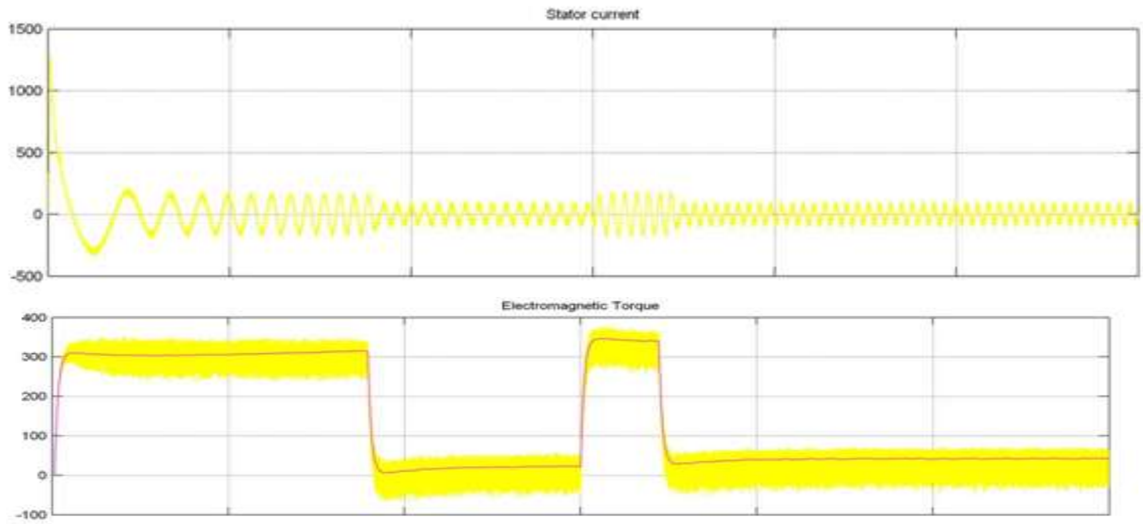
DTC Controller Block



Speed Controller of Conventional DTC

3.5.Results and Discussion

shows the speed torque response of the induction motor at different conditions i.e. for 0 to 1.5 seconds. The speed command 800 rpm is given and at this time load torque is at 0 Nm. When the speed command is changed from 800 rpm to 1000 rpm at 1.5 second, the load torque will be at 12 Nm. Also, at 1.5 second it can be seen from the Figure 4.9 that, if the speed command is suddenly changed then the induction motor produces a large electromagnetic torque, which is highly undesirable. Thus, in case of conventional DTC, the torque ripple is

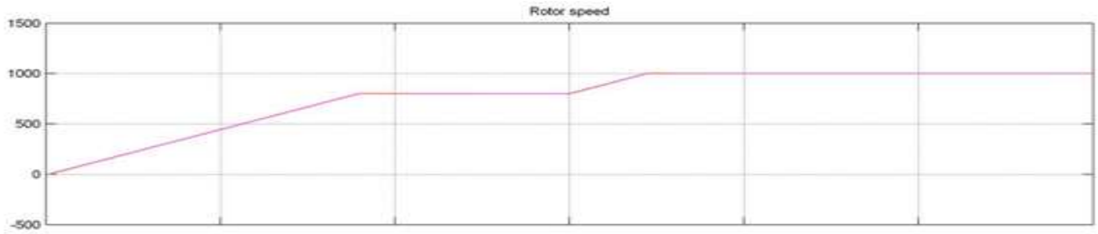


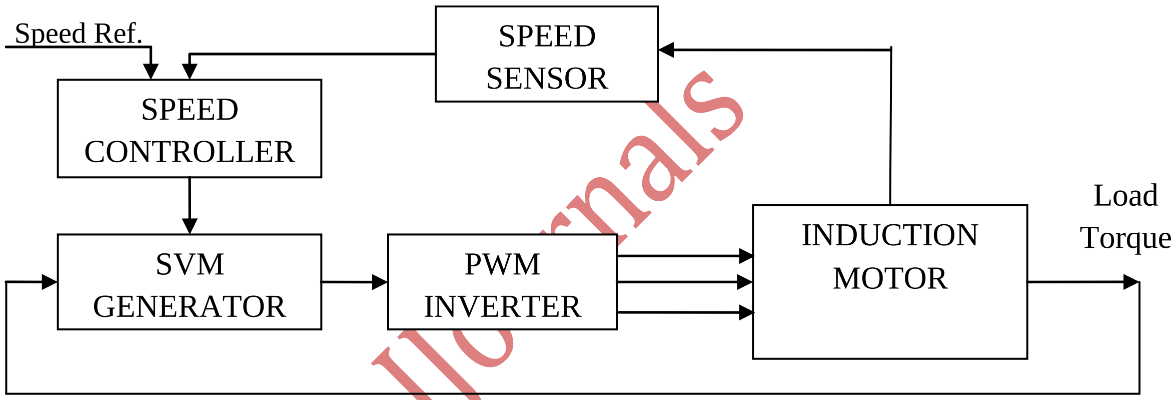
(±5) Nm.

4. SPACE VECTOR MODULATION (SVM)

4.1. Operating Principle of DTC-SVM

The operating principle of a variable speed electric drive (Induction Motor) is shown below which is controlled through the space vector modulation strategy.



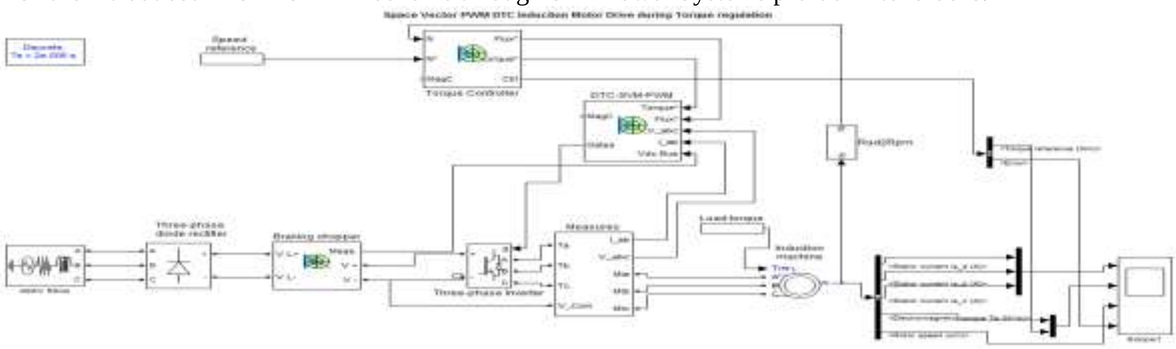


Operating Principle of Induction Motor Drive Controlled Through SVM

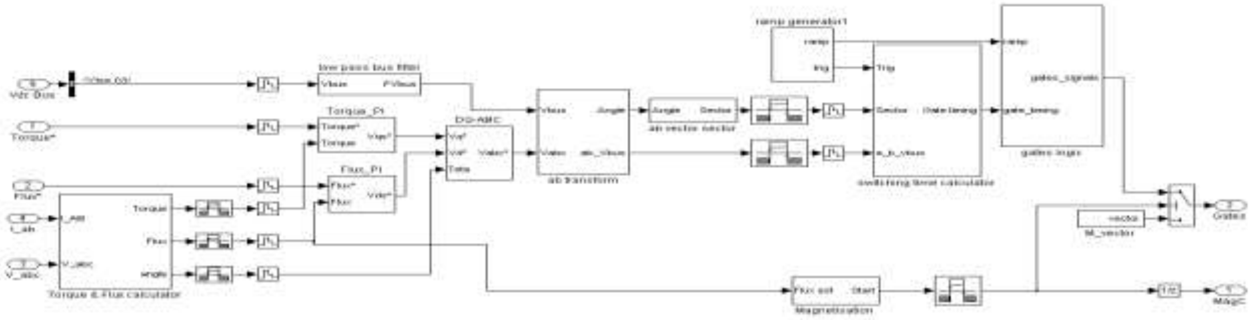
First of all, the actual speed is compared with the reference speed for the closed loop speed control. Here, the two PI controllers are used in speed controller which gives reference voltage and frequency to generate the three phase sinusoidal signal. These signals are used in SVM generator and based on the space vector position in the space, SVM calculate proper switching time for two consecutive switching vectors and also for zero switching vector and based on that vector, inverter gives supply to the induction machine.

4.2. Simulation Model of DTC-SVM

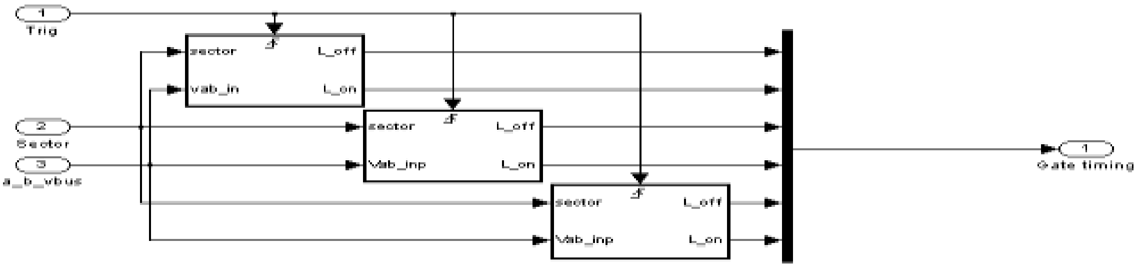
The supply of the induction motor is made from a three phase alternative voltage source with the help of the component using three phase rectifier, intermediate DC circuit, controlled three phase inverter and the elements which are introduced in SIMULINK scheme through SIM Power Systems pre-definite blocks.



Simulation Model of DTC-SVM



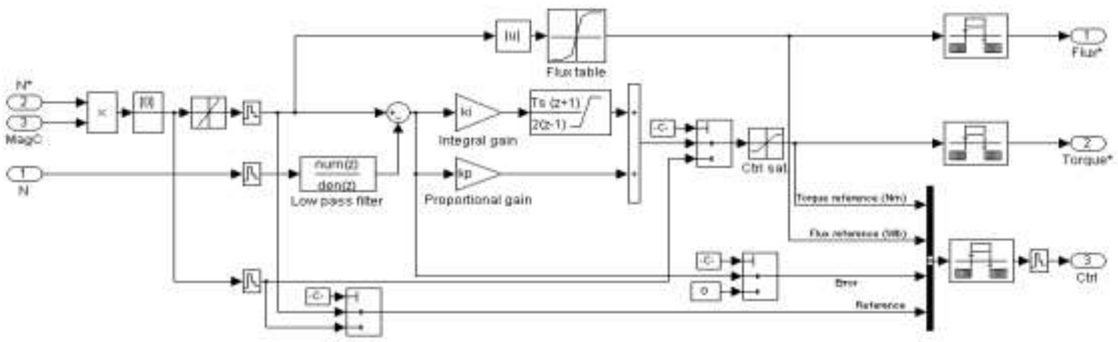
DTC-SVM Block



Switching time Calculator

4.3. Speed Controller Block

The speed controller (Figure) has inputs as:
a) The reference speed N* which is given by the Speed reference block,
b) The speed N obtained from the induction motor,



Speed Controller Block

And output of the signals as:
a) Freq.* (the reference frequency), b) Volts* (the reference voltage),
The first three output signals are the inputs to the SVM generator subsystem. Proportional integral (PI) regulator which controls the motor slip is the basis of speed controller. The PI regulator calculates the slip. Then, this slip value is added to the motor speed so as to produce the demanded inverter frequency. To maintain the motor V/f ratio constant, this inverter frequency is used to generate the required inverter voltage.

4.3.1. SVM Generator Blocks

The SVM generator, whose operating principle is presented in Figure, contains six blocks with the following functions:

- 3 sine waves with variable amplitude and frequency are produced by the 3-phase generator. The three signals maintain the difference of 120^0.
- The transformation converts variables from the 3-phase system to the 2-phase system.
- The sector calculator is used to find the sector in the plane (α-β plane) for the voltage vector; this plane is divided into six different sectors spaced by 60^0.
- The ramp generator generates a unitary ramp at the PWM switching frequency; which is used as time base for the switching sequence

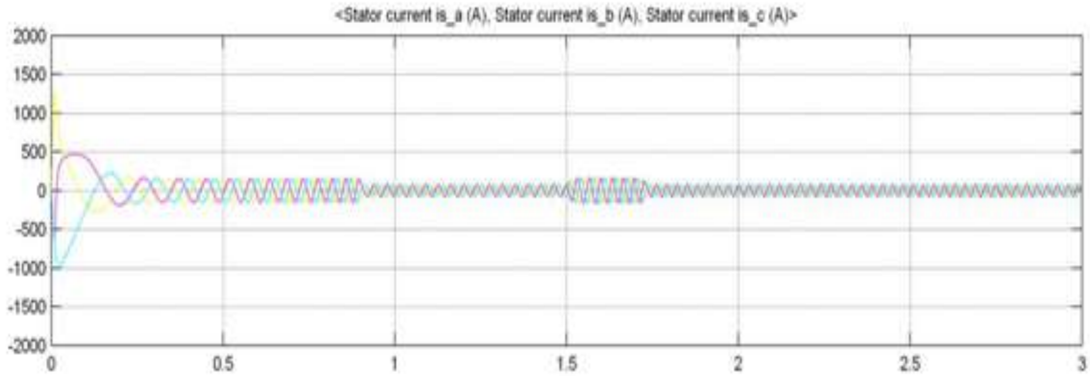
- Voltage vector time applied to the motor is calculated by the switching time calculator.
- Activation of inverter switches at right time is done by comparing the ramp and the gate timing signals by the gates logic.

5. RESULTS AND DISCUSSION

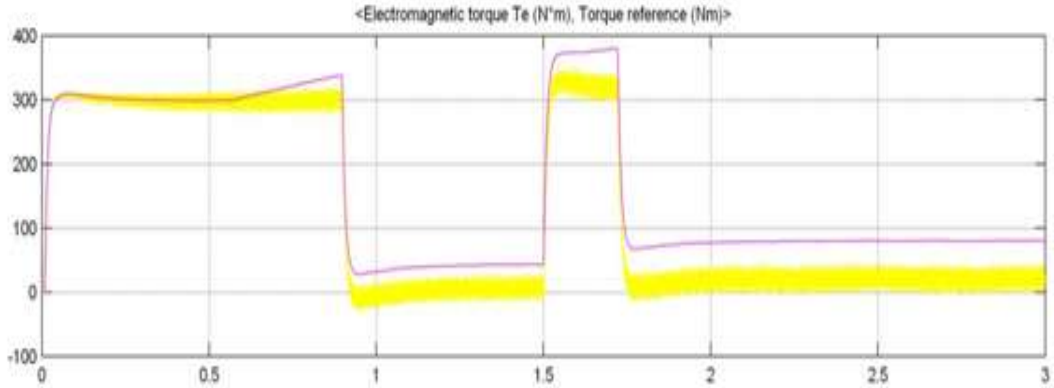
The control scheme is simulated with Matlab/Simulink, for following case as:

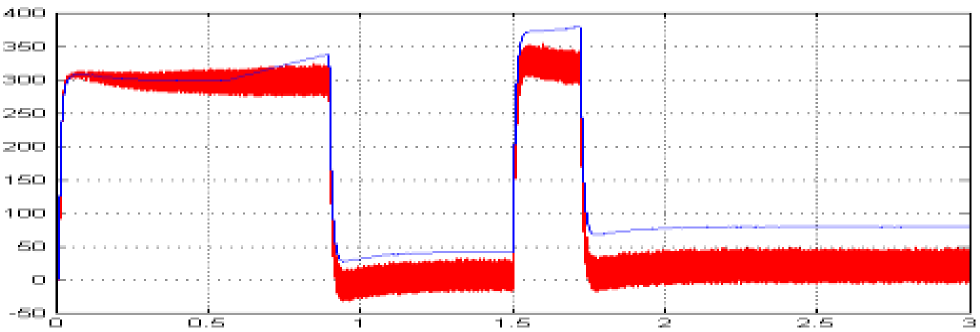
- At t = (0; 1.5) sec, the speed reference prescribed to (800; 1000) rpm.
- The load torque prescribed to (0; 12) Nm at t = (0; 1.5) s with step variation.

The variations in time of the main electrical and mechanical variables are obtained, specific to the presented drive (the stator current i_{sa}, the rotor current i_{ra}, the rotor speed N and the electromagnetic torque T_{em}) and it represents them in Figure

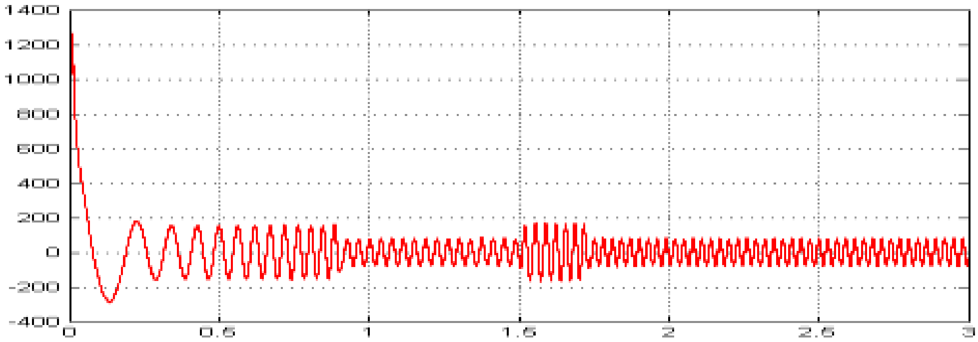


Time (Sec)

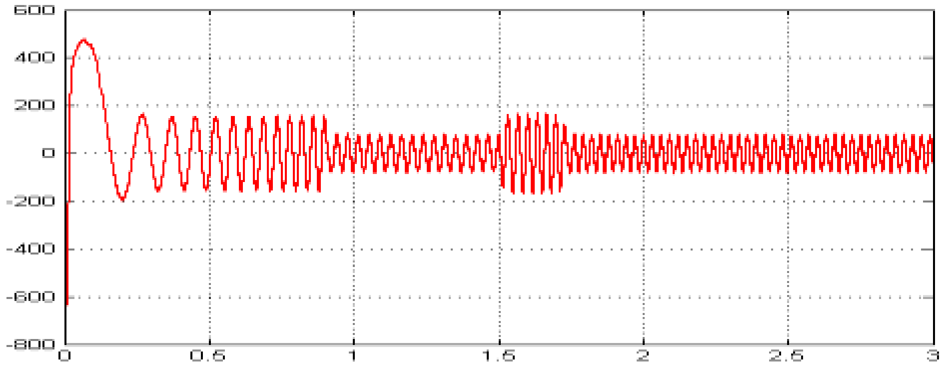




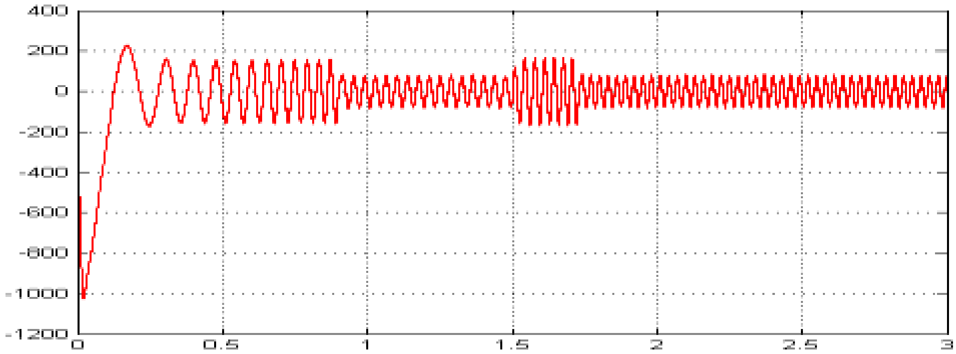
Torque (Nm) v/s Time (second)



Stator Current (Ampere) v/s Time (second)



Stator Current (Ampere) v/s Time (second)



Stator Current (Ampere) v/s Time (second)

6. CONCLUSIONS AND FUTURE SCOPE
7.

7.1. Conclusions

This thesis work presents a comparative analysis of conventional DTC and DTC-SVM. Space Vector Modulation direct torque control strategy is compared with the conventional direct torque control method according to their simulation results. It can be seen from the simulation results, that the torque ripples with DTC-SVM method is less than with conventional DTC scheme. From the simulation results of DTC induction motor drive, the following conclusion can be made:

- Steady State torque ripple is considerably reduced. As from simulation results it can be seen that the torque ripples in DTC-SVM is (±1.5) Nm, which is much less when compared to conventional DTC (±5) Nm.
- The flux ripples are reduced significantly in this case.
- The constant and controllable switching frequency is obtained in case of DTC-SVM.

7.2. Scope for Future Work

- Torque ripples can also be reduced by employing the duty ratio controller.

- The performance of the classical DTC can be improved by Softcomputing based DTC schemes.
- The simulation results can be validated by fabricating proto model.

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